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13. ABSTRACT ***(Maximum 200 Words)***

A biomass energy conversion project is being sponsored by the U.S. Environmental Protection Agency (EPA) to demonstrate an environmental and economically sound electrical power option for government installations, industrial sites, rural cooperatives, small municipalities, and developing countries. Under a cooperative agreement with EPA, Research Triangle Institute is initiating operation of the Camp Lejeune Energy from Wood (CLEW) biomass plant.

Wood gasification combined with internal combustion engines was chosen because of 1)recent improvements in gas cleaning, 2)simple, economical operation for units less than 10 MW, and 3)the option of a clean, cheap fuel for the many existing facilities generating expansive electricity from petroleum fuels with reciprocating engines. The plant incorporates a downdraft, moving bed gasifier utilizing hogged waste wood from the Marine Corps Base at Camp Lejeune, NC. A moving bulk wood dryer and both spark ignition and diesel engines are included. Unique process design features are briefly described relative to the gasifier, wood drying, tar separation, and process control. A test plan for the process optimization and demonstration of reliability, economics, and environmental impact is outlined.

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DEMONSTRATION OF A 1 MWe BIOMASS POWER PLANT AT USMC BASE CAMP LEJEUNE

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KEYWORDS

Engines, Fuel Drying, Fuel Feed, Gas Cleaning, Gasification, Power Generation

DEMONSTRATION OF A 1 MWe BIOMASS POWER PLANT AT USMC BASE CAMP LEJEUNE

A biomass energy conversion project is being sponsored by the U.S. Environmental Protection Agency's (EPA's) National Risk Management Research Laboratory, Air Pollution Prevention and Control Division utilizing funds from the U.S. Department of Defense's (DoD's) Strategic Environmental Research and Development Program. The project objective is to demonstrate an environmentally and economically sound power option for DoD installations, other federal and state agency installations, industrial sites, rural cooperatives, small municipalities, and developing countries. The Research Triangle Institute (RTI) is working under a cooperative agreement with the EPA to complete installation and operation of the Camp Lejeune Energy from Wood (CLEW) biomass plant for producing approximately 1 MW of electrical power at the Marine Corps Base Camp Lejeune. Thermal Technologies Incorporated and Mech-Chem Associates are promoting the gasifier technology and providing essential project support in the areas of equipment selection, plant construction, and computer control.

The CLEW plant utilizes only wood waste from the Base, which by regulations has to be diverted from the landfill. Utilizing waste biomass as a fuel for power generation eliminates sulfur dioxide emissions; produces zero net gain of carbon dioxide (CO_2); minimizes waste disposal problems, tipping fees, and the purchase of fossil fuels for electricity; provides energy security at domestic and international military installations; and promotes an exportable technology.

The project began with the consideration of several technologies for biomass-to-electricity conversion, including: a combustion boiler producing steam to drive a steam turbine (Rankine Cycle); a combustion boiler producing hot inert gas or heated air to drive a turbine; a gasification reactor to produce a gas to be combusted in a combustion boiler producing steam to drive a steam turbine; a gasification reactor to produce a gas to be combusted in a gas turbine; and a gasification reactor to produce a gas to be combusted in an internal combustion (IC) engine (spark ignited and/or compression ignited).

Gasification combined with IC engines was chosen although this technique has encountered several experimental failures in the past. Improved gas cleaning methods, successful preliminary tests, and a dedicated development team made this technology the best candidate for a demonstration. The process competes with other, more conventional processes which can operate economically at the small power plant scale (i.e., 0.5 to 10 MWe). A major objective is to address the niche, but potentially expanding, market of individual power units of less than 5 MWe. Another primary reason for the choice is to address the existing market

where diesel-fueled or other reciprocating generator sets are providing high-priced power in many remote locations. Engine conversion from petroleum fuel to clean biomass synthetic gas (syngas) is simple and, with the engine investment already in place, power costs may be cut an order of magnitude.

The plant design incorporates the ability to exercise either of two options: 1) sophisticated controls and automated materials handling for industrial or municipal sites, allowing two person plant operation; or 2) a more labor intensive, but considerably reduced investment, approach for process operation in developing countries or under-financed remote locations. To meet the latter requirement, the simplest fuel preparation is emphasized (e.g., hogged fuel, mechanically conveyed bulk drying using engine exhaust), complex reactor operation is avoided (simple moving bed, no exotic catalysts or filtration), and conventional engines are used.

Process Description

Figure 1 is a layout of the CLEW process. The fuel feed/drying system and gasification/power production equipment are housed on the Base inside a building 40 feet (12 meters) wide and 140 feet (43 meters) long. The Base provides wastewood fuel, including pallets, demolition waste, and cut trees and limbs. Wood waste is hogged by a tub grinder, screened, loaded, and transported in walking floor trailers from the Base landfill to the plant. The walking floor trailers become part of the feed system and automatically unload into a dryer. The dryer is a moving bed, down-draft system. Concurrently in the dryer, the bed of wood chips is mechanically conveyed horizontally while hot engine exhaust mixed with air is pulled down through the bed under vacuum and vented to the atmosphere. After drying, the chips move across a vibratory screen that separates out fines <1/4-inch (0.6 centimeter). A conveyor carries the wood chips to the top of the gasifier. The nominal fuel feed is about 2300 pounds (1043 kilograms) per hour of approximately 10% moisture wood.

The wood chips are gasified in a down-draft, moving bed reactor with a deep char bed below the pyrolysis zone. Wood chips and air enter the top of the gasifier with the air being preheated in a jacket around the cyclone which removes entrained fines from the syngas. The nominal air flow rate into the gasifier is about 390 scfm (0.184 sm^3/s) to provide combustion that gives a gasifier temperature distribution of about 1800 to 1300°F (982 to 704°C). The syngas leaves the reactor at the bottom through a manifold at a flow rate of about 1050 scfm (0.497 sm^3/s) and a higher heating value of about 170 Btu/scf (6353 kJ/sm^3). Char is removed from the bottom of the reactor through multiple, rotating "star" valves.

Char collects in the gasifier discharge cone, is removed through two screw conveyors separated by a lock hopper, and is transported to a dump truck. The char is mixed with coal fuel for a boiler located at the Base.

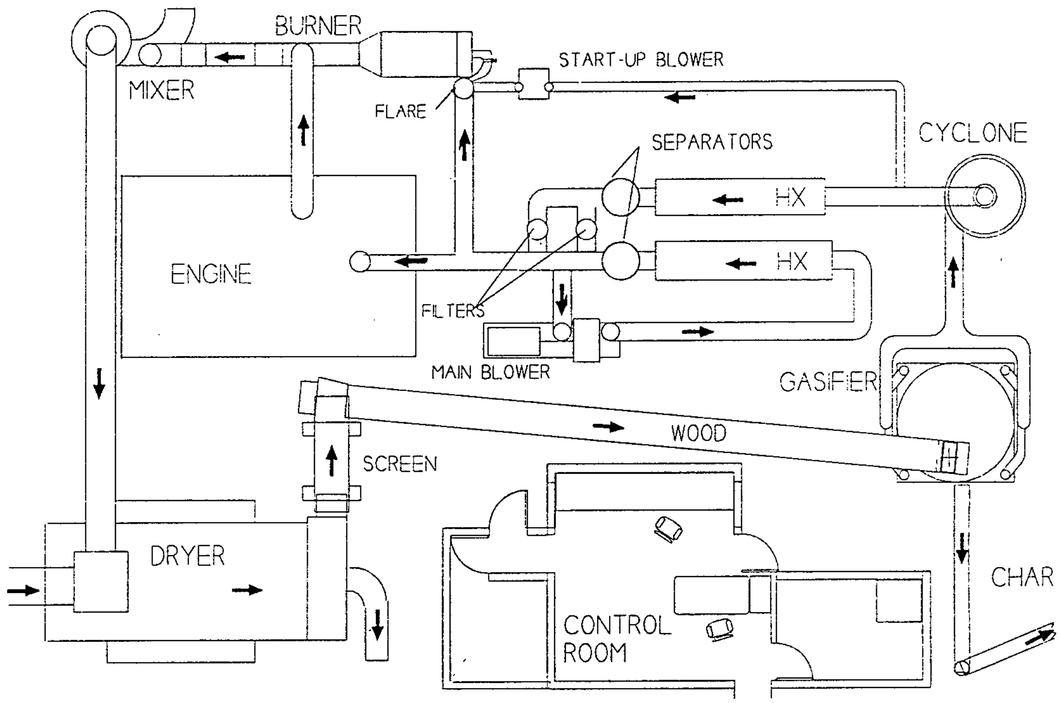

Fig. 1. CLEW process layout.

The syngas passes through the cyclone separator and then through a water/syngas heat exchanger. Next, a liquid separator removes tar and water from the syngas stream. A decanter separates the mixture with water sent to the Base's water treatment plant and the tar mixed with oil to power an oil-fired turbine on the Base. An impingement filter is used to further remove particulates and tar, followed by a multistage blower which maintains gas flow through the system. Another water/syngas heat exchanger cools the syngas (since the blower adds significant heat) and a second liquid separator sends more liquid waste to the tar/water separator for discharge and collection. After leaving the second liquid separator, part of the syngas is burned in a flare to the atmosphere. The remaining syngas flows to a syngas burner or to the engines. The syngas burner is used only to supply heat to the dryer when the engines are not running.

Two turbocharged engines driving generators are used to generate electricity: an 800 kW Waukesha L 7042 GSI and an Allis Chalmers or other diesel engine, using ~10% diesel fuel and 90% syngas (by heat value) generating 100 to 300

kW. Exhaust from the engines or the syngas burner is split between a stack and an air mixer, and the diluted hot exhaust is pulled through the dryer, under vacuum, by a variable speed blower. Two additional components of the plant are a cooling tower (supplying water to the gasifier char discharge cone, char screw conveyors, and water/gas heat exchangers) and a blower pushing air through the cyclone jacket.

The process is extensively instrumented to measure temperatures, pressures, and flow rate throughout the gas train; measure and analyze char, water, and tar produced; examine efficiency including all major auxiliary power units; evaluate wood drying; assess engine performance; and record maintenance and operating costs. Continuous gas analyzers measure carbon monoxide, hydrogen, CO_2, methane, and oxygen. Data acquisition and automated control of most operations are accomplished by Wonderware logic running on a Pentium 90 PC and by GE Fanuc 90/30 Programmable Logic Controllers (PLCs).

Some Distinguishing Characteristics and Early Results

Syngas production has not yet begun; therefore, results of the first phases of integrated process testing cannot be reported at this writing. However, the following describes a few unique design features and results from preliminary testing of single unit operations.

The down-draft gasifier operation has been upgraded from known designs to essentially continuous solid fuel input, maintaining a constant bed height based on accurate level detection and a constant reaction zone depth based on measured temperatures and mass balances. A rotating leveling rake is combined with a mechanical lever (whose position is measured by a potentiometer) to maintain an even pyrolysis zone. A deflector plate, which spreads wood chips from the gasifier wood inlet chute, is linked to a load cell whose measurement of dropping wood chip impacts is converted into a mass flow rate. The star valves, which control char removal, are of singular design and operate more intermittently since a half turn of these synchronized valves can remove the char equivalent of 5 minutes of fuel feed. The gasifier incorporates a previously recommended concept of a deep char bed (e.g., depth of 1.0 to 1.2 times reactor diameter). It is proposed that the deep char provide adequate active sites and residence time at high temperature to complete cracking of heavier tar constituents to lighter fractions. Wood fuel drying is a complimentary procedure, reducing required air for combustion heat and minimizing the latent heat loss for vaporization which cools the lower reactor bed. Air requirement is also reduced by preheating air in the cyclone jacket, at almost negligible operational cost.

For this project, conventional techniques of wood drying such as cascade or rotary driers were rejected because of high cost, complex operation, need for auxiliary fuels such as natural gas or propane, and/or because such equipment is usually sized for operations larger than CLEW. The dryer being used is a modified "forage box" (see Fig. 2) like those used for transporting and unloading farm silage. This is an enclosed trailer in which the floor moves from back to front and dried product exits via a cross-conveyor. All mechanics are operated from the power take-off shaft, to which a variable speed motor has been added, controlling the fuel feed rate to the gasifier. The down draft flow rate of hot exhaust gas mixed with air is optimized by controlling exit gas near saturation and by maximizing temperatures within safe limits. The unit has consistently produced wood moisture levels below 10% at design conditions, with blower power requirements lower than those anticipated because of low pressure losses through the packed bed. Operation at nominal temperatures has produced almost no devolatilization, with volatile organic compounds typically less than 55 ppm in the dryer exhaust. Minimizing wood fuel surface moisture from rainfall is also a significant help in increasing drying efficiency.

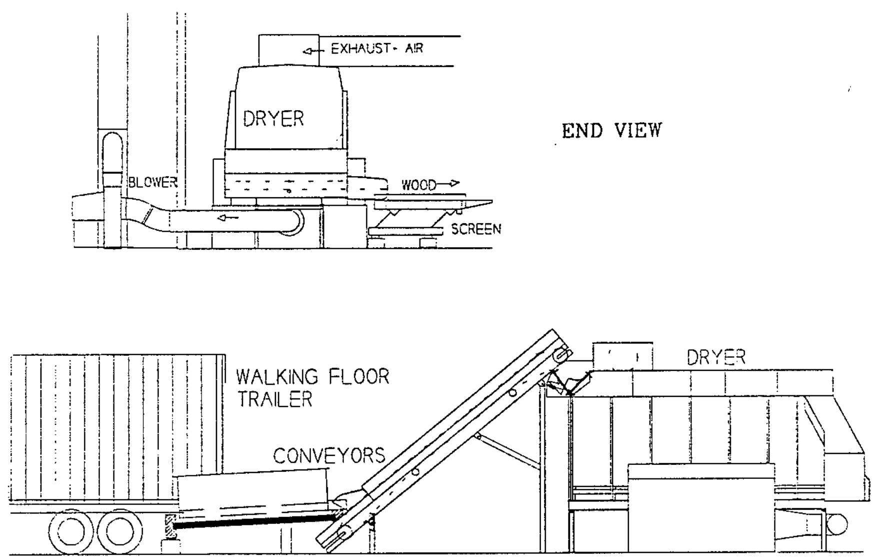

Fig. 2. Wood dryer elevations.

Fuel handling problems have been minimal to date. However, preliminary testing indicates that the downdraft gasifier pressure losses can be sensitive to fines buildup. Therefore, screening is implemented at both the landfill and the plant. It is found that, especially when care is not taken to avoid scooping dirt with wood into the tub grinder, fines through a 1/4-inch (0.6 centimeter) screen at the plant

can be as high as 3% of the fuel mass.

Liquid byproduct generation and recovery has not been tested at the CLEW plant, but tar and water samples have been recovered by RTI from previous tests with a similar downdraft gasifier. Over 95% of the heavy organics recovered are separable from water by gravity settling. The remaining water is found to contain up to 1% total organics with high ammonia concentrations. However, standard toxicity testing was consistently low-negative, and results demonstrated that water disposal to a conventional treatment plant (especially the Base facility where CLEW wastewater is a tiny fraction of the total) is a satisfactory option. The troubling tar fraction, in terms of impact on turbochargers and engine operation, is that fraction represented by submicron droplets. A newly designed impact, or impingement, filter is to be tried for capturing the bulk of these particles. Previous testing by others has indicated a need to reduce the tar concentration in syngas to near 50 ppm to avoid ultimate engine fouling.

The project will make an ambitious attempt to compare performance of the gas-fuel spark ignition engine with that of the diesel engine operating on syngas (with enough diesel fuel to ensure ignition). Attempts will be made to find the diesel operating conditions for minimizing the diesel fuel requirement.

While this first project will not physically address gasifier char as an activated carbon for water treatment, the project team is well aware of this potential. More than 1.2×10^6 Btu (1.3×10^6 kJ) is readily recoverable for superheat steam generation, and activated char value could match that of the electricity being generated. Iodine numbers for char from preliminary tests have approached 300.

Finally, a semi-empirical computer model in C++, called MERBAL, has been developed for computing mass and energy balances for the CLEW process. MERBAL makes use of all process data, including those which are apparently redundant, and incorporates statistical weights for parameters based on the estimated accuracy of their measurement. This allows calculation of what the measurements should be in the absence of experimental error. The method used in the program was first developed for the U.S. Department of Energy to analyze data from coal conversion processes. The model will represent the plant performance, and results will be compared to less sophisticated calculations of mass and energy balances.

Test Plan

A quality assurance/quality control plan and a plan for parametric testing and long-term operational demonstration are being implemented. The test modules,

covering a period of 12 months, are listed below. Long-term operation will augment the experiments and demonstrate the operational feasibility of the plant for providing power to the grid on a continuing basis. The main objective of the tests is to optimize operation.

Testing Modules

1) Startup and shutdown
2) Product gas throughput and turndown
3) Air/fuel ratio
4) Wood fuel moisture
5) Separator outlet temperatures
6) Filters
7) Diesel dual-fuel operation
8) Fuel size
9) Char bed depth
10) Long term

System parameters vital for high-performance operation are related to each of the test modules. These include: 1) minimum, safe gasifier heating and cooling times based on startup and shutdown protocols; 2) for the given equipment, maximum efficient, reliable throughput of product gas, and allowable turndown; 3) minimum air/fuel ratio while maintaining near-maximum syngas throughput at high efficiency; 4) correlation of wood fuel moisture content with the gasifier temperature distribution, tar and water production, syngas composition, and process efficiency; 5) correlation of separator temperatures with tar and water removal from the syngas; 6) influence of filter design and configuration on tar capture, tar accumulation in engine parts, and filter pressure drop and resulting blower power requirements; 7) minimum amount of diesel fuel required to maintain efficient operation and diesel engine efficiency; 8) effect of wood fuel size (e.g., 1/4-inch (0.6 centimeter) pellets, hogged wood, chunk wood) on tar production, dryer efficiency, gasifier and process efficiency, syngas composition, char characteristics, and pressure loss across the gasifier fuel bed; 9) influence of reduced char bed depth on the required pyrolysis zone volume, tar production, air/fuel ratio, gasifier efficiency, and gas composition; and 10) long-term process reliability, efficiency, operating costs, and emission/effluents.